



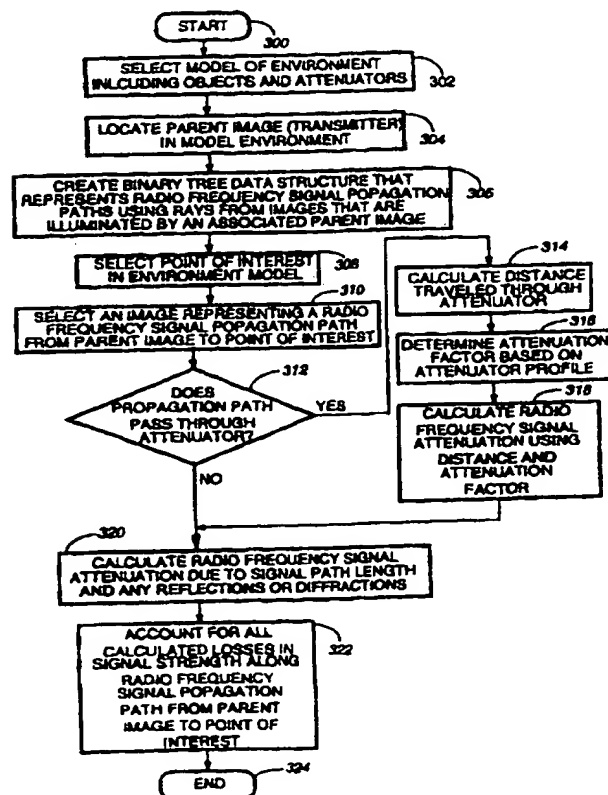
## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>6</sup> : <b>H04B 17/00</b>		(11) International Publication Number: <b>WO 98/04059</b>
<b>A1</b>		(43) International Publication Date: 29 January 1998 (29.01.98)
(21) International Application Number: PCT/US97/08569 (22) International Filing Date: 21 May 1997 (21.05.97) (30) Priority Data: 08/685,344 23 July 1996 (23.07.96) US (71) Applicant: MOTOROLA INC. [US/US]; 1303 East Algonquin Road, Schaumburg, IL 60196 (US). (72) Inventors: REED, John, Douglas; 1101 Brianclyff Drive, Arlington, TX 76012 (US). WANG, Shu-Shaw; 1803 Longbranch Court, Arlington, TX 76012 (US). (74) Agents: WARREN, Raymond, J. et al.; Motorola Inc., Intellectual Property Dept., 1303 East Algonquin Road, Schaumburg, IL 60196 (US).		(81) Designated States: CA, IL, JP, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  Published With international search report.

(54) Title: METHOD AND SYSTEM FOR CALCULATING A TRANSMITTED SIGNAL CHARACTERISTIC IN AN ENVIRONMENTAL MODEL HAVING ATTENUATOR FIGURES

## (57) Abstract

An environmental model that locates at least one object (206) and at least one attenuator (218) in relation to a transmitter (200) is selected. A data structure (100) that represents radio frequency signal propagation paths (234) using rays (244) from images in said environmental model is created, wherein the images (240) are illuminated by radio frequency signals from parent images (200). A point of interest (228) is selected in the environmental model. Using the data structure (100), an image (240) representing a radio frequency signal propagation path (234) to the point of interest (228) is selected. A change in said transmitted signal characteristic is calculated by determining if the radio frequency signal propagation path passes through the attenuator (218) and calculating a change in the signal characteristic as a result of propagating through the attenuator (218). Finally, the transmitted signal characteristic at said selected point of interest (228) is calculated in response to the calculated change in the signal characteristic.



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# METHOD AND SYSTEM FOR CALCULATING A TRANSMITTED SIGNAL CHARACTERISTIC IN AN ENVIRONMENTAL MODEL HAVING ATTENUATOR FIGURES

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## Field of the Invention

The present invention is related in general to calculating radio signal propagation, and more particularly to an improved method and system for calculating a transmitted signal characteristic in an environmental model using raytracing techniques.

10

## Background of the Invention

In a wireless communication system, such as a cellular telephone system or personal communications services (PCS) system, base station antennas should be located so that suitable radio signals are available everywhere in the service area.

One way to ensure adequate signal coverage in the service area is to copiously locate base stations and their antennas in the service area. This solution is not practical because purchasing base station equipment and leasing property for base station equipment and antennas is expensive. Therefore, communication systems providers attempt to lower the cost of the communications system by using a minimum number of base stations, each located so that its coverage area does not excessively overlap the coverage of another.

Another problem in locating base station antennas is obtaining adequate signal coverage in areas having various objects that impede radio frequency signal propagation. For example, in a business district or a downtown area of a higher-population city, such objects may include buildings, parking garages, and trees. The presence of these objects may require strategically placed base station antennas to provide adequate signal coverage in areas that might otherwise be in a blind spot.

To correctly locate base station antennas in a radio communications system, it is important to be able to accurately predict signal strength, or another signal characteristic, in the service area when a base station antenna is placed in a particular location. Such a prediction is the goal of many so-called raytracing programs. One problem with raytracing programs is that they don't accurately predict actual measured signal characteristics in the signal area. If a signal characteristic such as signal strength is over estimated, radio communications providers may spend more money than needed to provide communications services. On the other hand, if signal characteristics are under estimated, customers may be disappointed with the quality of services.

One reason raytracing programs are not more accurate in producing a signal strength picture is because the model used to predict signal propagation does not take into account some characteristic of the environment that affects the signal. Among other things, current raytracing programs analyze propagating signals which are reflected by walls of buildings and diffracted by corners of buildings. In modeling the coverage area, raytracing programs represent building walls as objects or panels. Each panel has properties that describe the affects of a wall on a propagating signal. Such properties include reflection coefficients and mathematical expressions that describe radio wave diffraction at the corner of the panel.

For further illustration, FIG. 1 depicts a transmitted signal reflecting off of an object or panel, and an associated reflected image. As shown, transmitter 20 is located relative to panel 22 in environment model 24. Environment model 24 represents, for example, a portion of the coverage area having buildings that redirect propagating signals radiating from a transmitter antenna. In this example, transmitter 20 is selected to radiate transmitted signals in a radiation pattern or arc defined by rays 28 and 30.

After leaving transmitter 20, transmitted signals propagate toward panel 22 and reflect off of panel 22 with a signal strength determined by

the material of panel 22 and the incident angle between the ray and panel 22. Thus, in FIG. 1, ray 28 reflects off of panel 22 to produce ray 32, and ray 30 reflects to produce ray 34. The signal strength of ray 32 depends upon the distance traveled by ray 28, incident angle 36, and the reflection coefficient of panel 22.

Note that the signals reflected off of panel 22, such as ray 32 and 34, can be represented as conceptual or virtual rays coming from another point source, represented here by child image 38, which can be thought of as the origin of rays 32 and 34. Representing reflected signals as signals transmitted from a child image is a means for simplifying the raytracing problem.

When propagating signals strike a corner, such as the corner of building 46 in FIG. 2, the transmitted signal is diffracted, as indicated by rays 48 and 50. Such a corner, which is called a diffraction corner, may occur at the end of a panel, such as the panels that make up building 46.

Because diffracted rays 48 and 50 behave as though they emanated from diffraction corner 52, diffraction corner 52 may be represented by a child image at the same location, which, again, simplifies the raytracing problem.

With reference now to FIG. 3, there is depicted a more complex environmental model of a communications system service area. If a system designer wants to know the total signal strength of a signal transmitted from transmitter 60 arriving at point of interest 62, the designer must consider signal power propagating directly from transmitter 60 to point of interest 62, as well as reflected and diffracted signal power arriving at point of interest 62. Thus, diffracted signals and signals reflecting off of buildings 64 and 66 may be modeled as rays coming from child images, and grandchild images. To make the problem tractable, the number of decendent images may be limited as specified by the user, or by an algorithm which considers the power contributed by each decendent image.

After locating images in the environment model, total signal strength at point of interest 62 may be calculated by accounting for contributions from transmitter 60 through ray 68, from child image 70 through ray 72, from child image 74 through ray 76, and from grandchild image 78 through ray 80. Image 78 is referred to as a grandchild image because that image is a child of a child image. That is, grandchild image 78 is energized, or receives energy from, child image 70. Note that grandchild image 78 is not energized by transmitter 60 (the parent image) because the path between transmitter 60 and grandchild image 78 is obstructed by panel 82.

As may be seen, it doesn't take a very complicated environmental model to produce a tedious calculation for determining the signal strength, or other signal characteristic, of a transmit signal at a point of interest. Furthermore, to be most useful, thousands of points of interest at specified intervals must be considered to produce a useful map of signal coverage in a service area.

With reference now to FIG. 4, there is depicted a tree 100, which is a data structure that may be used in raytracing programs to represent or aid in the calculation of signal propagation paths. In tree 100, each node, such as parent node 102, may point to, or be associated with, a child node, such as child nodes 104 and 106. Similarly, child nodes may point to a grandchild node, and a grandchild node may point to a great grandchild node, such as grandchild node 108 and great grandchild node 110. The same node, say node 108, may be a child node with respect to node 104 one level up, and a grandchild node with respect to node 102 two levels up. Thus, these child-node expressions are relative expressions.

The environment model in FIG. 3 may be represented as a tree. For example, transmitter 60 may be represented in tree 100 as parent node 102. Child image 70 in FIG. 3 may be represented as child node 104 in FIG. 4. Child node 104 is associated with parent node 102 because child image 70 derives its energy from transmitter 60. It may be said that child image 70 energized or illuminated by transmitter 60. Similarly, child image 74

may be represented in tree 100 by child node 106. Child nodes 104 and 106 have direct links to parent node 102 because child images 70 and 74 are directly energized by rays from transmitter 60 in FIG. 3. Child image 78, however, is energized by a reflection off of building 64. Therefore, child image 78 is represented in tree 100 as grandchild node 108. Any rays emanating from child node 78 that strike additional panels to create child images will be represented as a great grandchild node, such as great grandchild node 110. In this manner, the parent image, or transmitter 60, and derivative child images in FIG. 3 may be represented by a tree, such as tree 100 in FIG. 4.

To aid in calculating signal characteristics at a point of interest in the environment model, each node in tree 100 may be associated or linked with various types of data, including location of the node, type of node (reflection or diffraction), scope of the node (angles at which rays depart from the node). This technique for organizing data allows the raytracing program to calculate the effects of each bounce or diffraction along the path between the transmitter and the point of interest.

Even though raytracing programs tediously predict multiple signal paths and account for transmitted signal characteristics contributed by each of these paths, there are still differences between predicted signal characteristics and measured signal characteristics. To save money and insure quality service, it is important to eliminate or reduce the difference between predicted and measured values. Therefore, a need exists for an improved method and system for calculating transmitted signal characteristics in an environmental model that more accurately models a service area and predicts signal characteristics close to those that are actually measured in the modeled service area.

### Brief Description of the Drawings

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further objects, and advantages thereof, will best be

understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

**FIG. 1** depicts a transmitted signal reflecting off of a panel;

5 **FIG. 2** depicts diffraction of a transmitted signal;

**FIG. 3** illustrates an environment model of a wireless system service area;

**FIG. 4** depicts a data structure for representing the propagation of radio frequency signals in a raytracing program;

10 **FIG. 5** illustrates a data processing system that may be used to implement the method and system of the present invention;

**FIG. 6** depicts an environment model of a wireless communications system that locates objects and attenuators in relation to a transmitter antenna in accordance with an embodiment of the method and system of the present invention; and

15 **FIG. 7** is a high-level logical flowchart that illustrates the operation of an embodiment of the method and system of the present invention.

### **Detailed Description of the Invention**

With reference now to **FIG. 5**, there is depicted a data processing system 140, which may be used to implement an embodiment of the method and system of the present invention. Data processing system 140 may include processor 142, keyboard 144, display 146, and pointing device 148. Keyboard 144 provides means for entering data and commands into processor 142. Display 146 may be implemented utilizing any known means for displaying textual, graphical, or video images, such as a cathode ray tube (CRT), a liquid crystal display (LCD), an electroluminescent panel, or the like. Pointing device 148 may be implemented utilizing any known pointing device, such as a trackball, joystick, touch sensitive tablet or screen, track pad, or as illustrated in **FIG. 5**, a mouse. Pointing device 30 148 may be utilized to move a pointer or a cursor on display 146.



Processor 142 may be coupled to one or more peripheral devices, such as CD-ROM 150.

5 Data processing system 140 includes means for reading data from a storage device. Such means for reading data may include: a hard disk drive internal or external to processor 142 (not shown); a tape drive (not shown); floppy disk drive 152, which reads and writes floppy disks 154; or CD-ROM 150, which reads and/or writes compact disk 156. Such storage means may be referred to as a computer usable medium for storing computer readable program code in the form of data and software.

10 Data processing system 140 may also be coupled to a network which permits the transfer of data and software between data processing systems. Using such a network, programs can be loaded into data processing system 140.

15 The components of data processing system 140 discussed above may each be implemented utilizing any one of several known off-the-shelf components. For example, data processing system 140 may be implemented utilizing any general purpose computer or so-called workstation, such as the workstation sold under the name "Model 712/60" by Hewlett-Packard Company of Palo Alto, CA.

20 When performing a ray tracing simulation, it is important to model all objects in the service area that can affect the propagation of radio frequency signals between the base antenna location and the location of a subscriber unit. For example, trees and other foliage may be modeled to attenuate radio frequency signal power at rates that depend upon the type of foliage and the frequency of interest. In addition to an  
25 attenuation per linear distance travel through the tree or attenuator, attenuator models may also be non-linear. This means that an attenuation factor per unit distance through the attenuator may depend upon where on the attenuator figure the radio frequency signal enters the  
30 attenuator, and the angle of incidence between the ray entering the attenuator and the surface of the attenuator. Thus, a model of a tree may have a complex shape and a non-linear attenuation profile that depends

upon the point of entry into the attenuator, the angle of entry, and the path through the attenuator.

With reference now to FIG. 6, there is depicted an environmental model of a wireless communications system that locates objects and attenuators in relation to a base station transmitter antenna in accordance with the method and system of the present invention. As illustrated, transmitter antenna 200 is located near building 202. In this environmental model, buildings are formed by a plurality of panels. For example, building 204 includes panels 206 and 208 and additional panels (not shown) that form the other walls of building 204. Building 210 includes panel 212.

Also included in the environment model shown in FIG. 6 are attenuators, which in this example are trees 214 through 224. Although the attenuators in this example are trees, attenuators may be any object that changes a characteristic, such as signal strength, of a radio frequency signal without changing the direction of propagation for at least a portion of the signal. Other examples of attenuators include shrubs, billboards or signs, newsstands or other small structures, or other buildings that allow radio waves to propagate through, over, or around them.

In order to more accurately model trees 214 through 224, such trees may be represented by a compound three dimensional model that includes trunk 226 and foliage 218. Trunk 226 extends upward from the ground to a pre-selected height where the trunk ends and foliage 218 begins. In one embodiment, trunk 226 and foliage 218 are modeled with cylindrical shapes stacked one upon the other. Other attenuating objects may be modeled with appropriate three dimensional figures.

In the example of FIG. 6, the selected point of interest 228 is located in street 230. Point of interest 228 is the point in the environment model that is used for calculating the transmitted signal characteristic, which in one embodiment of the present invention is signal strength. To calculate signal strength at point of interest 228, several radio frequency signal propagation paths from transmitter antenna 200 to point of interest 228

may be considered. The paths shown in this example are only a small subset of the several radio frequency signal propagation paths that are possible. This subset was selected to illustrate the operating principles of the present invention.

5       The three radio frequency signal propagation paths shown in FIG. 6 are labeled with reference numbers 232 through 236. Notice that each signal path includes a change of direction as a result of either a reflection or a diffraction. Signal path 232 is reflected by panel 206. Signal path 234 is diffracted by diffraction corner 238. And signal path 236 is reflected by  
10       panel 212.

      Signal paths 232 and 236 are represented in a computer data structure with the aid of images 240 and 242, respectively. The modeling technique used in the present invention uses rays from images in the environment model to illuminate the point of interest. For example,  
15       image 240, which is located opposite transmitter antenna 200 along a perpendicular line that intersects panel 206, emits ray 244, a conceptual or virtual ray that can illuminate or radiate radio frequency signal power on an object located at point of interest 228. Notice that a portion of ray 244 represents the portion of radio frequency signal propagation path 232 after  
20       it has been reflected off of panel 206.

      Images 240 and 242 are represented in a data structure as locations in the environmental model from which radio frequency signals propagate. In a similar manner, diffraction corner 238 is also represented in the data structure as a source of radio frequency signals.

25       Of the signal propagation paths shown in FIG. 6, both radio frequency signal propagation paths 232 and 234 pass through an attenuator. Propagation path 232 passes through trees 216 and 218, and path 234 passes through tree 218. In more precise models according to the method and system of the present invention, the attenuation of signal  
30       strength, or other variation in signal characteristic, is dependent upon the distance traveled through the attenuator and the location of the propagation path in the attenuator. For example, propagation path 232

passes through an off-center portion of tree 216. Additionally, propagation path 232 does not pass through the trunk portion of tree 216. In contrast, propagation path 234 passes through the center of tree 218, and may also pass through trunk 226, depending upon the elevation of propagation path 234.

In an attenuation profile that describes the attenuation properties of particular attenuators, a signal that passes through the center of an attenuator may be attenuated at a different rate than a signal that passes through another portion of attenuator. In the case of a tree, this is because a radio frequency signal that passes through the center of a tree is more likely to hit larger branches or portions of the trunk, which would appear as a different loss per meter than the loss per meter at the outer fringes of the tree's foliage which has fewer branches.

With reference now to FIG. 7, there is depicted a high-level logical flow chart that illustrates the operation of an embodiment of the method and system of the present invention. As illustrated, the process begins at block 300 and thereafter passes to block 302 wherein an environmental model of at least a portion of the wireless communications system is selected. In this selected model, objects and attenuators are located relative to one another. Objects include buildings and structures (which may be modeled with panels) that can redirect a propagating signal transmitted from a transmitter antenna. Such redirection of a signal occurs through reflection or diffraction. Objects are used to model structures that are made of various materials. These materials are modeled with coefficients that are used to calculate the characteristics of reflected or diffracted signals. Thus, depending upon the material, reflected or diffracted signal characteristics are affected in different ways.

Attenuators include structures that modify a signal characteristic, such as signal strength, without substantially changing the direction of the propagating signal. An example of an attenuator is a tree. Attenuators may be modeled as three dimensional figures, or as compound figures, as in the trees having a foliage part and a trunk part

discussed above. These attenuators may also have an attenuation profile that describes how an attenuation factor varies depending upon the location of the signal path in the attenuator. This means that propagating signals passing through the center of a tree may be attenuated at a different rate than a signal propagating through the outer edge of a tree.

Next, the parent image or transmitter image is located in the model, as depicted at block 304. Selection of the parent image is allowed so that proposed transmitter locations may be evaluated for signal coverage in the environment model.

Once the transmitter has been located, the process creates a data structure, such as a binary tree data structure, that represents radio frequency signal propagation paths using rays from images that are illuminated by an associated parent image, as illustrated at block 306. When an image is illuminated by a parent, that image receives its signal power from an associated parent image. For example, image 240 is illuminated by its parent image, transmitter antenna 200. The association between image 240 and its parent, transmitter antenna 200, may be illustrated by the fact that image 240 would not exist if transmitter antenna 200 was not there.

Next, a point of interest is selected in the environment model, as depicted at block 308. Points of interest are typically selected at locations where a subscriber unit is likely to be found. In the example shown in FIG. 6, point of interest 228 is selected in street 230. In order to develop a map that represents a selected signal characteristic over an entire coverage area, such a point of interest is iteratively selected at different locations in the environment model.

After selecting a point of interest, an image that represents at least a portion of a radio frequency signal path from an associated parent image to the point of interest is selected, as illustrated at block 310. One way to select such an image is to look for an image, from the point of view of the point of interest, that is not blocked by another panel (not counting the panel responsible for generating the reflected image). For example, in

FIG. 6, three images are visible from point of interest 228—images 240 and 242, and diffraction corner 238.

After selecting an image, the process determines whether or not the radio frequency signal propagation path associated with the selected image passes through an attenuator, as depicted at block 312. Thus, if image 240 is the selected image, the process determines whether or not the signal propagation path associated with image 240—signal path 232—intersects or passes through an attenuator. In the case of signal path 232, the signal passes through two attenuators—tree 216 along a leg of signal path 232 that is before the reflection, and tree 218 along the leg of signal path 232 after the reflection.

In some embodiments of the present invention, signal path 232 may be analyzed in three dimensions. Thus, in a three dimensional model, the process may determine whether or not signal path 232 passes above or below the foliage of tree 216. In the case where a compound figure is used, the process may determine whether or not the signal path passes through the foliage portion of a tree or the trunk portion of a tree.

If the signal propagation path passes through an attenuator, the process calculates the distance that the propagating signal traveled through such an attenuator, as illustrated at block 314. In the case where the attenuator is modeled as a cylinder, this involves calculating the length of a chord formed by the intersection of the cylinder and a line representing the signal path. That is, calculating the length of the line between the entry point and the exit point of the attenuator.

Thereafter, the process determines the attenuation factor based upon the attenuator profile, as depicted at block 316. Such an attenuator profile describes how the attenuator attenuates a propagating signal depending upon the location of the signal path in the attenuator. Such an attenuator profile may specify, for example, that a signal passing through the center of a tree is attenuated more per unit distance than a signal entering the fringes or outer edges of the tree. Such an attenuator profile may also include information about signal attenuation based upon

an incident angle between the signal path and the surface of the attenuator. Such an incident angle may require more analysis when the angle is not so predictable, as when the shape of the attenuator is a polygon rather than a circle

5       After the attenuation factor and the distance traveled through the attenuator are known, the process calculates the radio frequency signal attenuation that results from passing through the attenuator, as illustrated at block 318. Although the embodiment described in the flow chart of FIG. 7 calculates radio frequency signal attenuation, other signal  
10 characteristics may be calculated as a result of more complex models which combine signal scattering from leaves, diffraction, reflection, transmission, and attenuation, in combination for the estimated sizes, density and distribution of the leaves. Statistical averages relating the radio frequency properties may also be used on tree parameters, including  
15 foliage density, moisture content, size, shape, and type of tree. These more complex models can be used to obtain an attenuation for a path, modeled as a ray, that passes through the foliage.

With reference again to block 312, if the propagation path does not pass through an attenuator, the process calculates the radio frequency  
20 signal attenuation due to signal path length, including signal paths before and after any reflections or diffractions, and attenuation due to any reflections or diffractions, as depicted at block 320. Thus, the radio frequency signal attenuation due to free air propagation between transmitter antenna 200 and panel 206, and between panel 206 and point  
25 of interest 228 are calculated. In addition to free air attenuation over the length of the path, any attenuation that occurs during the reflection off of panel 206 is also calculated.

And finally, the process accounts for all calculated losses in signal strength along the radio frequency signal propagation path from the  
30 parent image to the point of interest, as illustrated at block 322. This accounting includes losses calculated in block 320 and in block 318 if the propagation path passes through an attenuator.

Before ending at block 324, the process may loop from block 322 back to block 310 to select additional images that are capable of illuminating the selected point of interest. This allows signal strength calculations at a point of interest to consider signal power received from multiple signal propagation paths. Examples of other images that can illuminate point of interest 228 include image 242, which is associated with a path that does not pass through an attenuator, and image 238, which is a diffraction corner associated with a signal path that passes through tree 218, and maybe through trunk 226.

10 Additionally, the process may also iteratively loop back from block 322 to block 308 to select a new point of interest in a process that constructs a map showing signal characteristics at all points in the environment model.

As indicated above, aspects of this invention pertain to specific method functions implementable on computer systems. In an alternate embodiment, the invention may be implemented as a computer program product for use with a computer or data processing system. Those skilled in the art should readily appreciate that programs defining the functions of the present invention can be delivered to a computer in many forms, which include, but are not limited to: (1) information permanently stored in non-writable storage media (e.g. read-only memory devices such as ROM chips, or CD-ROM disks 156—readable by a computer I/O attachment such as CD-ROM reader 150); (2) information alterably stored on writable storage media (e.g. hard disk drives and floppy disks 154); or (3) information conveyed to a computer through communication media, such as a network, the public switched telephone network, a fiber optic cable, and transmitted radio frequency signals. It should be understood, therefore, that such media, when carrying computer readable instructions that direct the method functions of the present invention, represent alternate embodiments of the present invention.

Although the method and system of the present invention has been described with an example that calculates signal strength in a service



area, those persons skilled in the art should recognize that other signal characteristics, such as a bit error rate, or a signal delay spread, may be calculated.

5 As described above, the method and system of the present invention more accurately predicts transmitted signal characteristics, such as signal strength, in a model of a communications system service area. More accurate predictions enable system designers to provide quality communications services without the cost of over designing the system with overlapping signal coverage between cell sites. More accurate  
10 predictions also expose signal coverage problems, which may then be fixed before customers are annoyed by poor service.

The foregoing description of a preferred embodiment of the invention has been presented for the purpose of illustration and description. It is not intended to be exhaustive or to limit the invention  
15 to the precise form disclosed. Modifications or variations are possible in light of the above teachings. The embodiment was chosen and described to provide the best illustration of the principles of the invention and its practical application, and to enable one of ordinary skill in the art to utilize the invention in various embodiments and with various  
20 modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the invention as determined by the appended claims when interpreted in accordance with the breadth to which they are fairly, legally, and equitably entitled.

### Claims

What is claimed is:

1. A method for calculating a transmitted signal characteristic in an environmental model, said method comprising the steps of:
  - 5 selecting an environment model that locates at least one object (206) and at least one attenuator (216) in relation to a transmitter (200);  
creating a data structure (100) that represents radio frequency signal propagation paths (232) using rays (244) from images (240) in said environmental model, wherein said images (240) are illuminated by  
10 radio frequency signals from parent images (200);  
selecting a point of interest (228) in said environment model;  
using said data structure (100), selecting one of said images (240) representing a radio frequency signal propagation path (244) from said parent image to said point of interest (228);
  - 15 calculating a change in said transmitted signal characteristic resulting from signal propagation over said radio frequency signal propagation path (232) from said parent image (200) to said point of interest (228) by:
    - determining (312) if said radio frequency signal propagation  
20 path passes through said attenuator (216);  
calculating a change (318) in said signal characteristic as a result of propagating through said attenuator; and  
calculating (320, 322) said transmitted signal characteristic at said selected point of interest in response to said calculated change in said  
25 signal characteristic.

2. The method for calculating a transmitted signal characteristic according to claim 1 wherein said at least one attenuator is a tree, and wherein said step of selecting an environment model that locates at least one object and at least one attenuator in relation to a transmitter includes  
5 selecting an environment model that locates at least one object and at least one tree in relation to a transmitter.

3. The method for calculating a transmitted signal characteristic according to claim 1 wherein said at least one object is a reflection panel,  
10 and wherein said step of selecting an environment model that locates at least one object and at least one attenuator in relation to a transmitter includes selecting an environment model that locates at least one reflection panel and at least one attenuator in relation to a transmitter.

15 4. The method for calculating a transmitted signal characteristic according to claim 1 wherein said at least one object is a diffraction corner, and wherein said step of selecting an environment model that locates at least one object and at least one attenuator in relation to a transmitter includes selecting an environment model that locates at least one  
20 diffraction corner and at least one attenuator in relation to a transmitter.

5. The method for calculating a transmitted signal characteristic according to claim 1 wherein said transmitted signal characteristic is signal power.  
25

6. The method for calculating a transmitted signal characteristic according to claim 1 wherein said attenuator is a cylindrical representation of a tree, and wherein said step of determining if said radio frequency signal propagation path passes through said attenuator further  
30 includes determining if said radio frequency signal propagation path passes through said cylindrical representation of a tree.

7. The method for calculating a transmitted signal characteristic according to claim 1 wherein said change said attenuator has upon said transmitted signal characteristic is a function of the path through said attenuator, and wherein said step of calculating a change in said signal  
5 characteristic as a result of propagating through said attenuator further includes calculating a change in said signal characteristic as a result of propagating along a particular path through said attenuator.

8. A system for calculating a transmitted signal characteristic in  
10 an environmental model comprising:

means for selecting an environment model that locates at least one object and at least one attenuator in relation to a transmitter;

means for creating a data structure that represents radio frequency signal propagation paths using rays from images in said environmental  
15 model, wherein said images are illuminated by radio frequency signals from parent images;

means for selecting a point of interest in said environment model;

means for using said data structure, selecting one of said images representing a radio frequency signal propagation path from said parent  
20 image to said point of interest;

means for calculating a change in said transmitted signal characteristic resulting from signal propagation over said radio frequency signal propagation path from said parent image to said point of interest  
by:

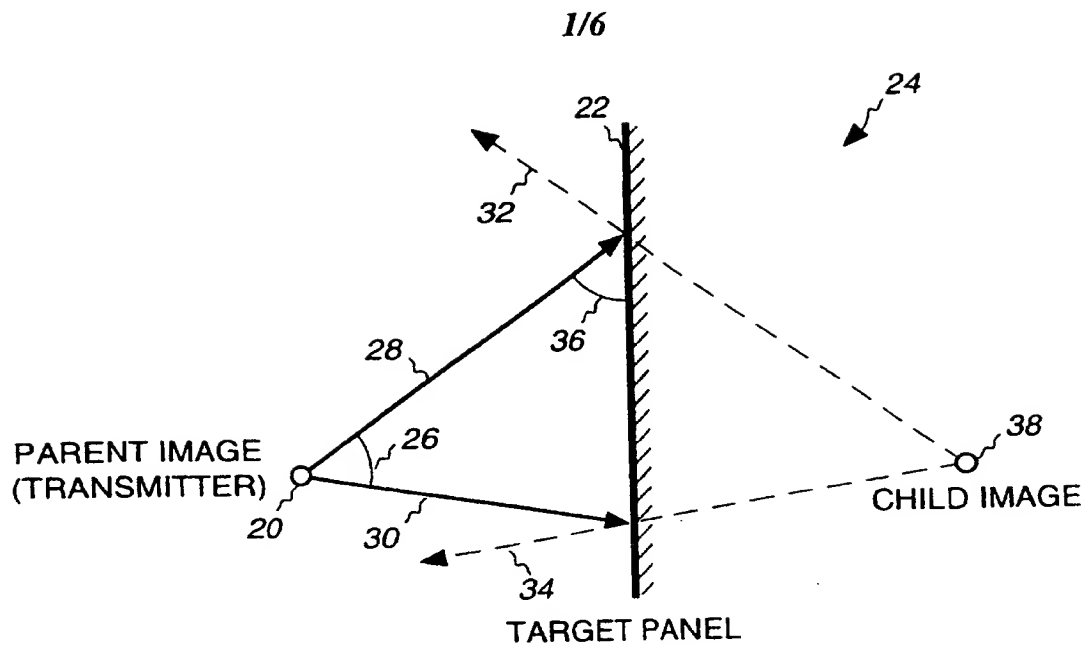
25 means for determining if said radio frequency signal propagation path passes through said attenuator;

means for calculating a change in said signal characteristic as a result of propagating through said attenuator; and

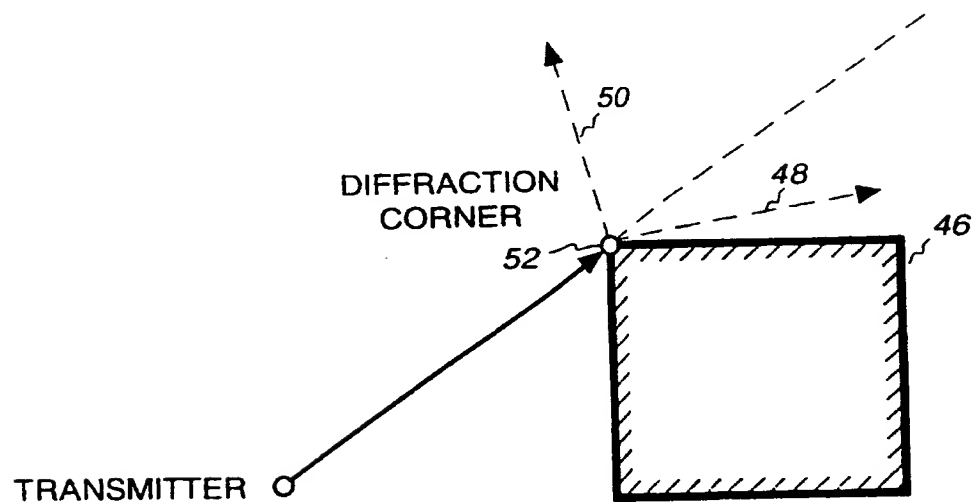
means for calculating said transmitted signal characteristic at said  
30 selected point of interest in response to said calculated change in said signal characteristic.

9. The system for calculating a transmitted signal characteristic according to claim 8 wherein said at least one attenuator is a tree, and wherein said means for selecting an environment model that locates at least one object and at least one attenuator in relation to a transmitter  
5 includes means for selecting an environment model that locates at least one object and at least one tree in relation to a transmitter.

10. The system for calculating a transmitted signal characteristic according to claim 8 wherein said attenuator is a representation of a tree including a cylinder shaped trunk portion and a cylinder shaped foliage  
10 portion, and wherein said means for determining if said radio frequency signal propagation path passes through said attenuator further includes means for determining if said radio frequency signal propagation path passes through said representation of a tree including a cylinder shaped  
15 trunk portion and a cylinder shaped foliage portion.

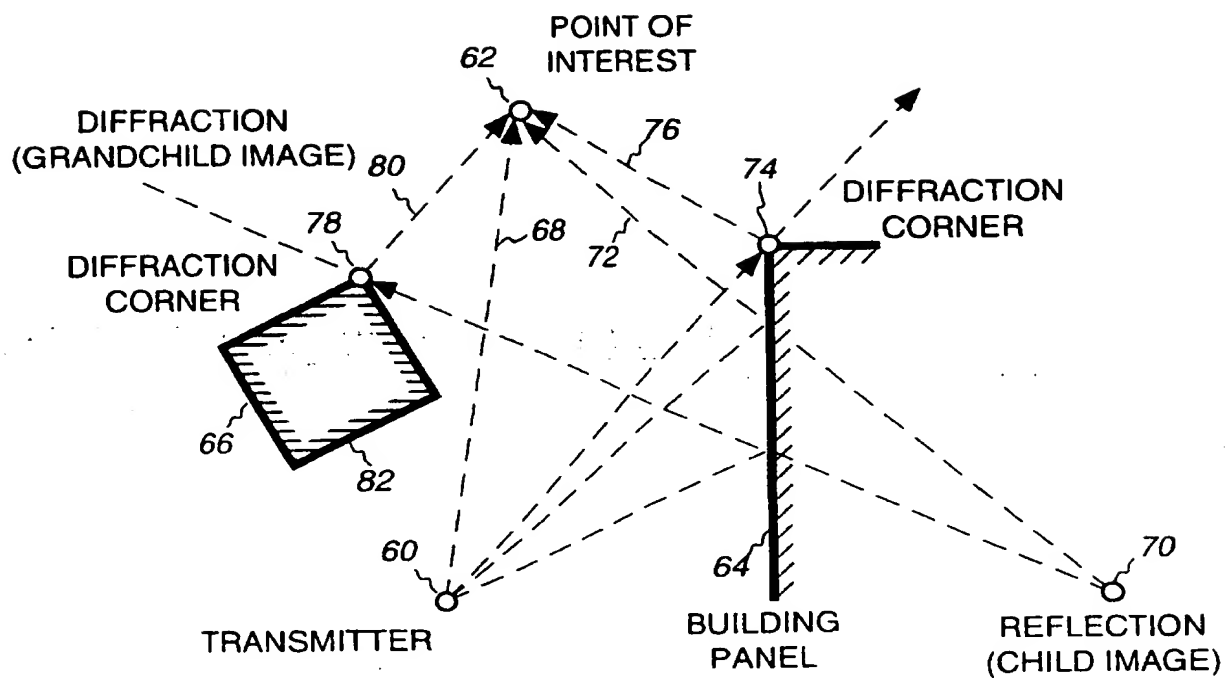


Prior Art  
**FIG. 1**

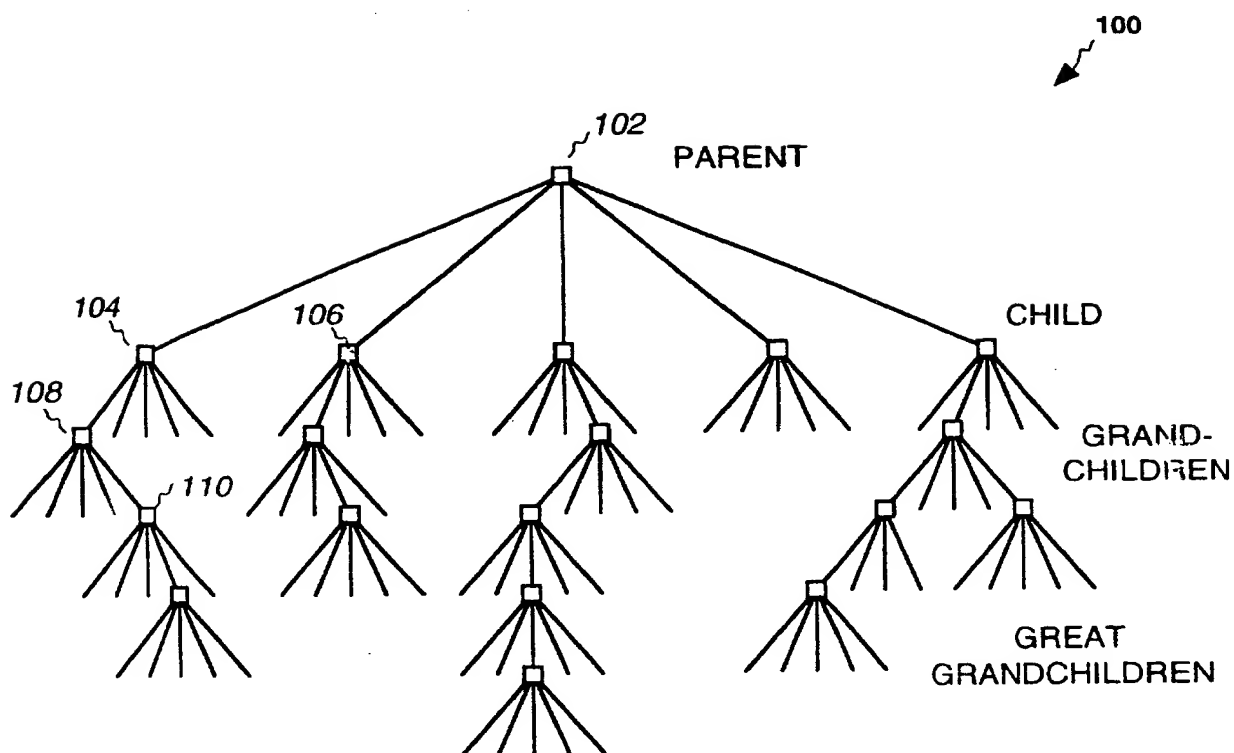


Prior Art  
**FIG. 2**

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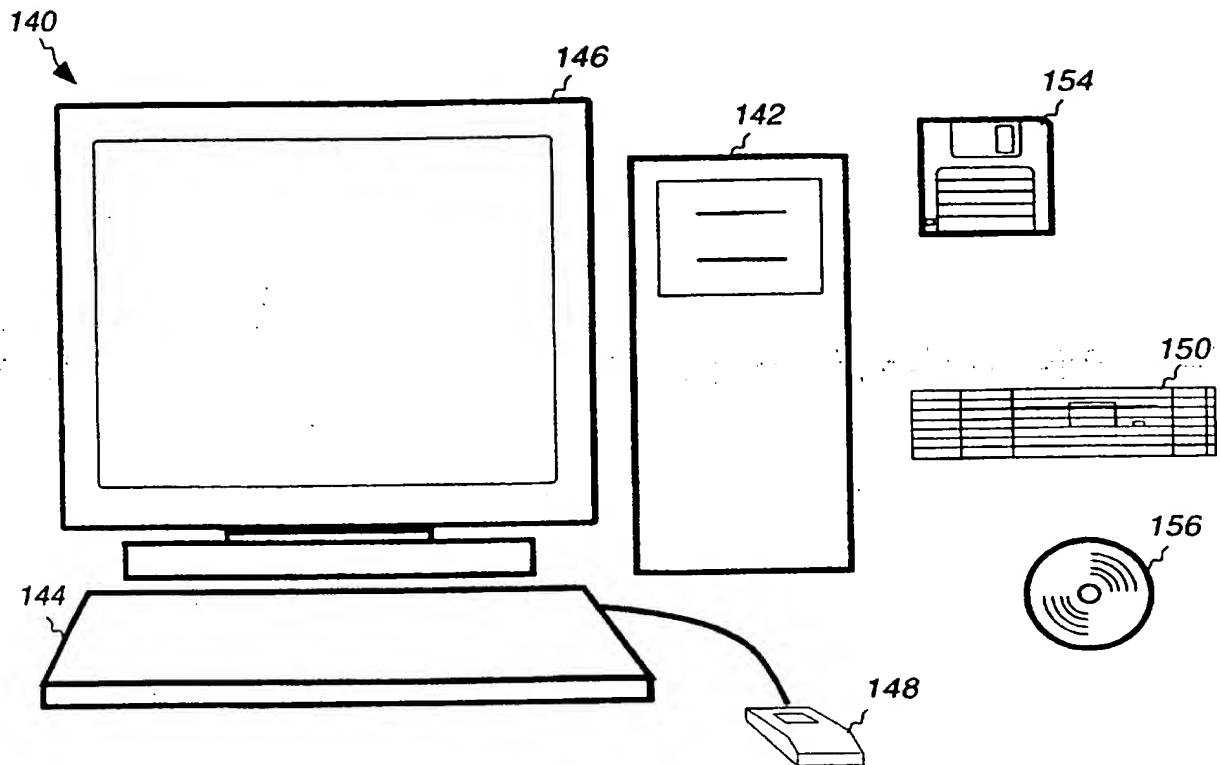
**FIG. 3**

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**FIG. 4**



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**FIG. 5**

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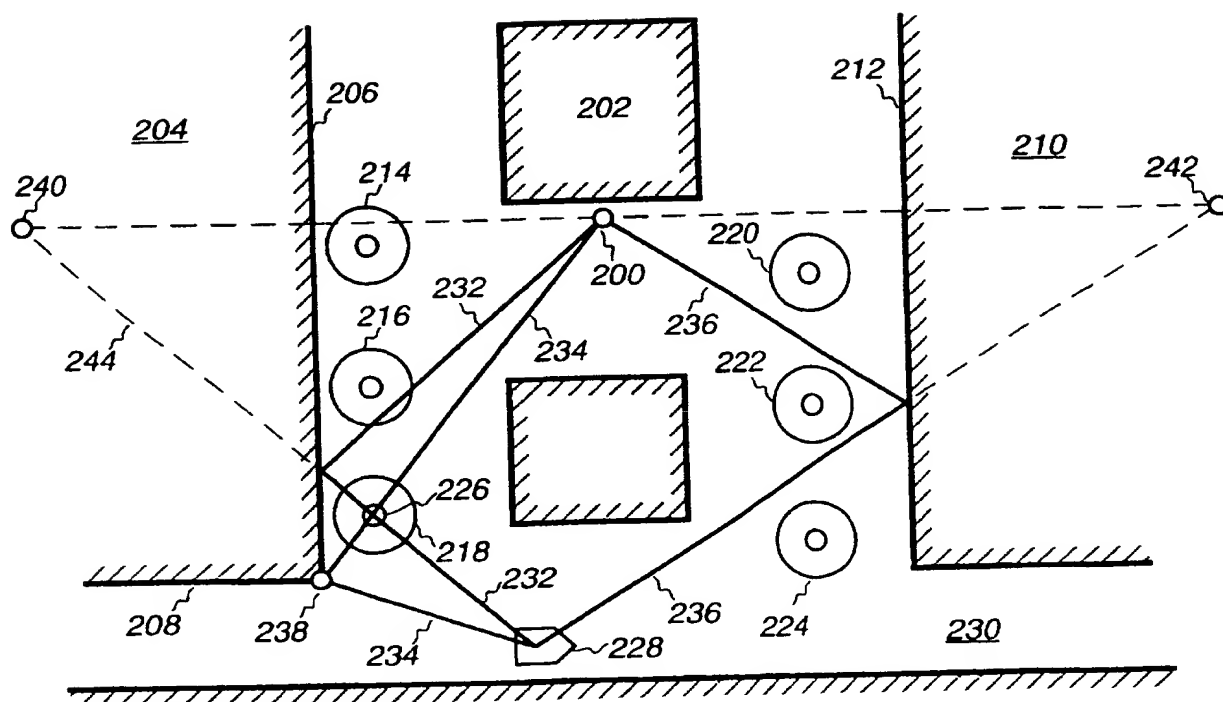
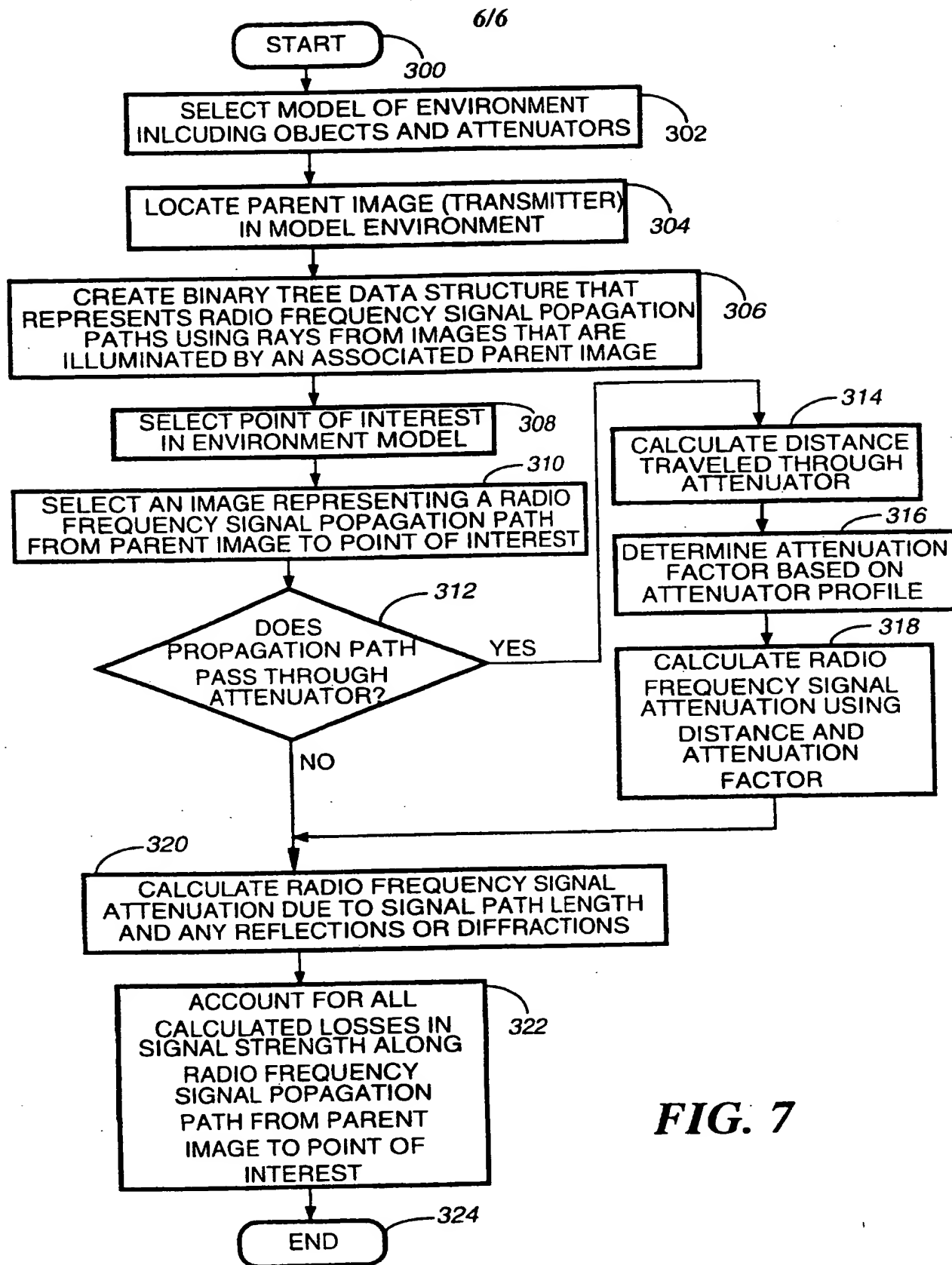


FIG. 6

**FIG. 7**

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US97/08569

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04B 17/00

US CL :455/67.1

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 455/67.1, 67.3, 67.4, 67.6, 67.7, 422, 423, 424, 507, 517, 62, 63, 115

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS: RAY TRACING

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X, P	US 5,623,429 A (FORTUNE ET AL) 22 APRIL 1997, see figs. 3-4.	1-9, 12-21, 24-33, 36
X	US 5,450,615 A (FORTUNE ET AL) 12 SEPTEMBER 1995, see figs. 1-5.	1-9, 12-21, 24-33, 36
A, P	US 5,574,466 A (REED ET AL) 12 NOVEMBER 1996, see figs. 1-4.	1-36



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:	* T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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* O* document referring to an oral disclosure, use, exhibition or other means		
* P* document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

07 AUGUST 1997

Date of mailing of the international search report

03 SEP 1997

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